APPENDIX H
STREAM TEMPERATURE MODELING

Methods: SNTEMP Modeling

The use of a temperature model allowed simulation of stream temperatures under varying target condition scenarios. Simulations included current conditions and naturally occurring conditions based on higher levels of streambank vegetation, flow augmentation, and reduced width to depth (W:D) ratios. Simulations determined the relative influence of streambank vegetation, flow augmentation, and reduced W:D ratios on stream temperature by modeling each one of these components individually.

SNTEMP, the Stream Network Temperature Model, is a mechanistic heat transport model that predicts daily mean and maximum water temperatures at the end of a stream network (Theurer et al., 1984, Bartholow, 2004). Model simulations occur over a single time step, such as a day, and evaluate the effects of changing shade, stream geometry, and flow on instream temperature. The model requires inputs describing stream geometry, hydrology, meteorology, and stream shading.

Input Parameters

The model requires a basic suite of input data describing stream conditions and other factors during the modeling period. Three broad categories of input data include meteorology, stream geometry, and hydrology.

Local weather stations at Ovando and Helmville supplied the meteorological data. Meteorological data are mean values for the modeling period, and consists of:

- Air temperature
- Relative humidity
- Wind speed
- Cloud cover, presented as a percent of possible sunshine
- Solar Radiation

Values for solar radiation were not available for the modeling periods from the local weather stations. In lieu of solar radiation values, the model calculates solar radiation if values for dust coefficient and ground reflectivity are available. Dust coefficient and ground reflectivity values representative of the season and ground cover for the modeling period were used (Tennessee Valley Authority, 1972).

Hydrologic data are mean values for the modeling period, and include stream discharge throughout the system and water temperature. Instantaneous flow measurements taken during the late summer of 2006, supplied low flow data. Temperature sensors deployed for the summer of 2006 supplied the temperature data. Sensors at 13 locations collected hourly stream temperature on the impaired streams and important tributaries. Nine sensors were on Union Creek and four were on Elk Creek. These temperature data allowed development of model input files representative of typical summer hot periods.

Analysis of temperature data consisted of displaying hourly temperature data, the medians and ranges of temperature measurements, and seven-day average maximum water temperatures in a series of graphs and box and whisker plots. The hourly temperature data throughout the summer illustrates the timing of temperature increases as well as diurnal fluctuations. The box and whisker plots illustrate changes in temperature between sites, and the seven-day average maximum temperature graphs show the period of highest temperatures and their duration. Together, these figures provide temporal, statistical, and spatial descriptions of summer water temperatures.

Initial flow at the beginning of the modeled stream, tributary flow, ground water flow, point sources into the stream, and any flow diversions characterize flow throughout the system. Water temperature is input into the model at the beginning of the network, at any locations where additional flow enters the network, and at calibration points.

Significant Stream Temperature Controls and Target Selection

Surface Diversion

Landowners in the Lower Blackfoot irrigate approximately 5,345 acres of cropland by a combination of sprinkler and flood methods. Reduced in-stream flow volume that results form diversion and warmed flood irrigation returns increase the human caused thermal loading to streams when naturally occurring temperatures are most limiting for fish and supporting aquatic life. In addition, conversion from flood to sprinkler irrigation methods over the past 25 years and simultaneous expansions in irrigated area have diminished return flows and reduced the thermal assimilative capacity of streams. Irrigation best management practices are available that increase the amount of diverted water actually consumed by the crop, reduce diversion requirements and improve the thermal assimilative capacity. Lacking a water budget based irrigation diversion plan for Elk or Union creeks, a conservatively low expectation of 15 percent flow augmentation is assumed to be available on these streams.

Shade

One of the datasets required by the temperature model describes the amount of total shade from topography, vegetation and channel morphology. Literature-based values for vegetation canopy, field data describing bank vegetation type and extent and interpretation of aerial and ground photos helped quantify channel shade from vegetation. The four vegetation shade parameters of average canopy height (Vh), canopy diameter (Vc), canopy offset from the channel (Vo), and canopy filtering value were estimated for each woody vegetation type. The measured extent of woody bankline vegetation types, with their characteristic shade values allowed calculation of a weighted average shade for each temperature impaired reach. Aerial photo interpretation identified vegetation type for reaches without measured base parameter data. Topographic shade was assessed by interpreting digital elevation data. Channel cross section data, collected as part of the 2006 sediment impairment investigation, helped estimate shade contributed by channel shape.

Reaches of both Union Creek and Elk Creek occur as narrow channels meandering through herbaceous meadows of grass and sedge cover. Some shading occurs within such reaches due to the height (2 to 3 feet) of these plants adjacent to narrow channels. Current condition shade values used in the temperature modeling include that provided by herbaceous cover in addition to shade derived solely from woody vegetation. Total shade values that are based on varying filter properties, bankline extent, canopy diameter and channel offset provide an accurate estimate of overall shade for use in the temperature model (Bartholow, 2004).

Along most of the temperature listed segments, riparian vegetation has degraded to the extent that corresponding increases in thermal loads are significant. Therefore, riparian vegetation shading, as represented by bankline vegetation extent, is the principal temperature target for streams on the 303(d) List in the Lower Blackfoot planning areas.

Channel Morphology

Channel morphology influences stream temperatures. Riparian vegetation overhanging a narrow stream has a larger cooling effect than equivalent vegetation along a wider stream. Wide streams are more susceptible to thermal heating than narrow ones simply due to larger exposure area. An increase in stream bank vegetation has a smaller mitigating effect on thermal gain than the same increase along a narrow channel. The naturally occurring condition for channel width to depth ratio is one that meets and maintains the ratio targets developed by channel type in **Section 5.0** for sediment and habitat impairments. Since some reaches currently meet width to depth targets, this parameter is not considered a significant source of increased temperature loading. From a restoration perspective, improvements to riparian cover that increase shade should allow establishment of stable geomorphic channel conditions.

In summary, the temperature target parameters include the following:

1. An extent of woody bank vegetation that prevents stream temperature increases above those allowed by the B-1 standard,
2. 15 percent increase in channel flow volume provided by irrigation system improvements,
3. Channel W:D ratios developed in response to sediment and habitat impairments.

Limitations within the SNTEMP model or lack of information prevent model consideration of other human or natural temperature controls such as turbidity, dissolved organics or beaver activity.

Naturally Occurring Shade Conditions

Thick stands of woody vegetation occur locally on stream banks in the Lower Blackfoot Planning area. Examples of these conditions redpectively for valley bottom and upland channels occur at the following locations:

- Union Creek (reach Union2) in the NW ¼ Section 3, Township 12 North, Range 15 West.
- Camas Creek (reach Cam1) in the SW ¼ Section 8, Township 12 North, Range 15 West.

Aerial images of these examples are illustrated in **Appendix G, Figures G-1 and G-2**.

Through the process of developing bankline vegetation extent as a shade parameter, conditions along relatively undisturbed stream banks in valley areas were interpreted as representing 80 percent steam bank woody vegetation extent. Within mountain reaches, 90 percent stream bank woody vegetation cover occurs along undisturbed banks. These estimates of reference condition applied to temperature impaired streams and significant tributaries through the model markedly increased shade and reduced stream temperatures. These extents of woody bankline vegetation are considered achievable given successes reestablishing riparian areas where standard BMPs have been implemented.

A series of Stream Network Temperature (SNTEMP) models provide simulated stream temperatures under current conditions and under improved vegetation (shade), flow, and width conditions. Because 80 to 90 percent woody bankline vegetation was assumed as the naturally occurring shade condition for all temperature impaired tributary segments, the temperature changes simulated under this shade condition were selected as representing the naturally occurring temperature. In addition, a flow increase of 15 percent to current stream flows, and reductions in W:D ratio, where appropriate, define naturally conditions in Union Creek and Elk Creek.

Sections below pertaining to Elk Creek and Union Creek contain tables specifying input data for each of the models. These sections describe meteorological, hydrological, and stream geometry input data for each model. Conditions represent the modeling period.

Model Networks

Each model required development of a spatial model network consisting of multiple stream segments. Each stream segment is unique and has homogenous characteristics such as length, stream width, slope, channel roughness (Manning’s n), shade, and flow. Delineation of each segment occurs through identification of a series of nodes along the model network, and these nodes specify values for some or all of the segment characteristics (**Table H-1**).

Table H-1. SNTEMP model network nodes and stream characteristics described with each node

Node Type	Input Stream Characteristics
Headwater	Latitude, elevation, stream distance, water temperature, flow, stream width, Manning’s n, shade
Segment	Latitude, elevation, stream distance, stream width, flow, Manning’s n, shade
Point	Stream distance, water temperature, flow
Diversion	Stream distance, flow
Calibration	Stream distance, water temperature
Temperature Output	Stream distance
Flow	Stream distance, flow
End	Stream distance, flow

Headwater and segment nodes define the upstream point at which a stream segment begins, and that segment's stream characteristics. Segment nodes also define the downstream extent of a stream segment, but not its characteristics. Point nodes are additions of flow to the modeled stream, and can define the location and flow of important tributaries. Diversion nodes specify flow removed from the network. Flow nodes redefine the quantity of instream flow, and account for lateral flow such as groundwater. End nodes define the downstream extent of a stream or the network. Temperature predictions occur at these nodes. Additionally, temperature predictions occur at any point in the network where a temperature output node exists.

Model Calibration

After model construction, calibration of simulated water temperatures with observed water temperature data is necessary. The goal of calibration is to ensure that the temperatures simulated with SNTEMP match well with observed conditions. The model is then suitable for assessing potential restoration efforts and conditions related to TMDLs.

To calibrate each model, observed daily mean and maximum water temperatures are assigned to calibration nodes at the end of each network and at various points within the network. A comparison of observed temperatures with simulated daily mean and maximum water temperatures at those points is used to assess how well the model is simulating temperatures. For SNTEMP, a model is accurate if the difference between observed and simulated temperatures is no greater than 0.5^{o} C (0.9^{o} F) (Bartholow, 1989).

Calibration of simulated to observed water temperatures is accomplished by changing model input parameters in successive calibration iterations until simulated temperatures match observed temperatures. Parameters can be modified singly or in combination. Parameters modified include those described in SNTEMP literature (Bartholow, 1989, Bartholow, 2004) and fit with the project team's knowledge of the modeled streams. The parameters considered for modification during calibration were:

- relative humidity,
- cloud Cover,
- wind,
- dust coefficient,
- ground reflectivity,
- thermal gradient, and
- Manning's n (for maximum temperatures only).

Sections below contain tables for Elk Creek and Union Creek specifying the parameters modified and the simulated temperatures for each calibration run. These sections also describe the rationale for each change in parameters. Calibration results at multiple nodes in a model network illustrate the accuracy of the model at multiple locations within each network.

Model Simulation

Once calibrated, the models can simulate resultant changes in water temperature from varying shade, flow, or channel width. Since lack of riparian shade is a large contributor to high temperatures in the modeled streams, changes in temperature were largely due to this parameter.

Output from the simulations was used to determine the change in temperature from current conditions due to changes in shade, flow, or width, and the amount of shade required to meet temperature targets. Simulations typically include:

- current stream conditions,
- natural stream conditions (defined by Montana DEQ, usually flow augmentation by 15 percent, decreased W:D ratio, and 80 percent or 90 percent streambank vegetation and corresponding increase in shade,
- several simulations that determined the change in stream temperature from, and therefore the relative influence of, changes in only shade, flow, or width, and
- one simulation of the target values for shade.

The temperature targets are those affecting mean daily temperatures due to uncertainty in the model's ability to simulate maximum daily temperatures. The target simulation predicts a mean temperature that is no more than the allowable 1.0 °F or 0.5°F increase, depending upon the simulated mean temperature under naturally occurring conditions. Simulation results for mean daily maximum temperatures are reported as well. **Section 8.2** of the main document contains tables and graphs listing which parameters were changed in each simulation, the degree of change, and the resulting temperatures for each simulation.

Model Sensitivity and Sources of Uncertainty

The most sensitive meteorological inputs to the SNTEMP model are air temperature, relative humidity, solar radiation and wind speed (Bartholow 1989). The use of local weather stations to supply required meteorological inputs introduces uncertainty as to whether the station data reflects actual conditions throughout the modeled networks. Actual air temperatures, humidity and sunlight conditions vary throughout the planning area with elevation, vegetation effects on near surface wind velocity and drainage aspect. This variability is not precisely reflected in the weather station data that are mean values for the modeling period.

Percent shade is also a sensitive input parameter for which the vegetation component was derived from literature values for community types and aerial estimates of bankline vegetation. These indirect means of deriving vegetation shade will inherently vary from field measurements of canopy shade using a densiometer.

Stream temperature is highly sensitive to discharge. The model inputs for hydrologic data are mean values for the modeling period based upon instantaneous flow measurements taken during the late summer of 2006, when flows were low. Variation from these means as well as variations in estimated diversion and ground water recharge volumes and ground water recharge introduces additional uncertainty. These uncertainties can partially offset in defining the modeling period as hottest part of the growing season, approach likely to develop more restrictive target values for temperature controlling factors. The model's use of mean input values for the modeling period limits the accuracy of output for daily maximum stream temperatures.

Elk Creek Model

The Elk Creek model simulated temperatures for a 6.2-mile stretch of Elk Creek from below Cap Wallace downstream to its confluence with the Blackfoot River. This segment of Elk Creek is listed as being temperature impaired on the 2006 303(d) List.

Construction

Nodes in the model identify where hydrology, stream geometry, and temperature data are input in the stream network. There are no point sources from tributary streams in the Elk Creek model (**Figure H-2**). Calibration points for Elk Creek are immediately below Sunset Hill Rd, below Route 200, and at the mouth. Two water diversion points exist for Elk Creek. One of these is located just downstream from the initiation point of the model, below Cap Wallace. Elk Creek also had water diverted below Sunset Hill Road.

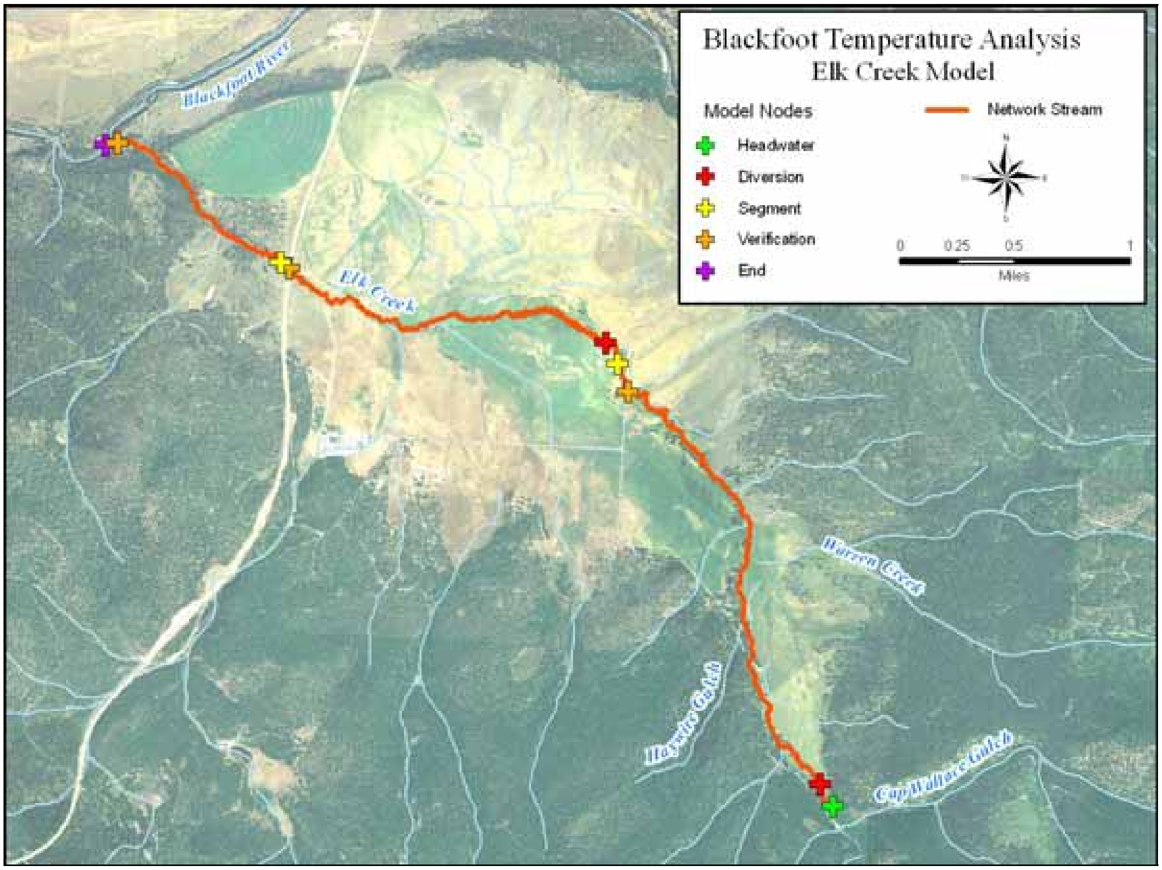

Figure H-1. Schematic of the Elk Creek model network and model nodes

Modeling of Elk Creek is for the period July 23 – July 24, 2006. A two-day modeling period ensured that water completed travel from the top to the bottom of the network. **Table H-2** lists stream geometry and general vegetation characteristics for the lower Nevada Creek model. About 8.5 percent of Elk Creek streambanks have woody vegetation. While the average low flow width is 8.9 feet, much of Elk Creek above Route 200 has a width of 5 feet or less. This accounts for roughly 5 miles of the total 6.1 miles of the stream length modeled.

Table H-2. Stream conditions for the Elk Creek SNTEMP model.

Stream	Modeling Period	Length (mi)	Average Low Flow Width (ft)	Average Bankline Vegetation (%)	Average Shade (%)
Elk Creek	July 23 - 24, 2006	6.2	8.9	8.5	19.9

Table H-3 lists data input into the model. For each segment and headwater node, flow, width, Manning's-n, and shade must be designated, while water temperature is required for headwater nodes. All other nodes require only water temperature and/or flow data.

Table H-3. Input data for the Elk Creek model

Stream	Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Shade (%)	Comments
Elk Creek	Below Cap Wallace to Sunset Hill Rd	Headwater*	6.2	62.0	2.8	9.5	0.062	26.7	
		Diversion	6.0		0.4				Directly below Cap Wallace
		Calibration	3.6	67.0	2.5				At Sunset Hill Road
	Sunset Hill Rd to Route 200	Segment	3.4		2.5	8.4	0.062	12.0	
		Diversion	3.4		0.2				Directly below Sunset Hill Rd
		Calibration	1.2	71.7	2.3				At Route 200
	Route 200 to the Blackfoot Rive	Segment	1.1		2.3	8.5	0.062	19.2	
		Calibration	0.1	72.0	2.0				At mouth to Blackfoot River
		End	0.0		2.0				Blackfoot River

Meteorological data for the modeling period July 23 – July 24, 2006 were summarized and input into the model (**Table H-4**). These data are representative of hot and dry conditions that cause water temperature extremes. The average daily mean temperature, 77^{o} F, represents a hot period in the summer of 2006.

Table H-4. Meteorological input data for the Elk Creek SNTEMP model

Modeling Period	Air Temperature (F) (mean)	Relative Humidity (%) (mean)	Wind (mph) (mean)	Possible Sun (%)	Dust Coefficient	Ground Reflectivity
July 23 - 24, 2006	77	43.2	3.3	90	0.05412	0.28110

Calibration

The Elk Creek model required a few iterations to complete calibration. The initial model run for Elk Creek simulated mean daily temperatures 3.17^{o} F, 2.77^{o} F, and 3.09^{o} F greater than observed temperatures at the locations below Sunset Hill Rd, below Route 200, and at the mouth above the Blackfoot River, respectively (**Tables H-5 through H-7**). These differences between simulated and observed mean temperatures are not within the margin for calibration of 0.9^{o} F, therefore calibration was necessary for the entire stream.

Meteorological data was least reliable in terms of characterizing conditions found on the stream, as the weather stations that provided data are located off the stream. To calibrate the model, relative humidity was decreased to 25 percent and sunshine was decreased to 85 percent. This resulted in mean daily temperatures below Route 200 and at the mouth that were within the 0.9^{o} F margin for calibration. However, the simulated mean temperature at Sunset Hill Road was still too high. Increasing wind speed to 4 mph lowered temperatures further. This yielded simulated mean daily temperatures higher than observed temperatures by 0.79^{o} F below Sunset Hill Road and lower by 0.54^{o} F and 0.38^{o} F below Route 200 and at the mouth, respectively. These values were within the margin for calibration for all sites.

To improve the model's performance for maximum temperature, Manning's n was increased from 0.062 to 0.080 for all segments in the model. Manning's n was adjusted because changes in this parameter only affect maximum temperatures in the model. The SNTEMP model uses the Manning's n parameter to capture the appropriate mixing depth and travel time of the stream. The result of changing Manning's n to 0.080 "speeds up" the stream and lowers simulated maximum temperature by 1.25^{o} F at the mouth, 3.78 ^{o} F above the observed maximum temperature. Further increases in Manning's n did not occur, however, as higher values for Manning's n are unrealistic. In addition, there is uncertainty in the capability of SNTEMP to predict daily maximum temperatures accurately (Bartholow, 2004).

Table H-5. Initial model and calibration results for Elk Creek at Sunset Hill Road

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	67.01	75.52	NA	NA	NA
Initial Model Run	70.18	81.81	3.17	6.29	Default Parameter Values
1	68.14	78.82	1.13	3.30	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85%
2	67.80	78.82	0.79	3.30	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85% Wind Speed Increase to 4.0 MPH
3	67.80	77.65	0.79	2.13	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85% Wind Speed Increase to 4.0 MPH Manning's n Increase to .08

Table H-6. Initial model and calibration results for Elk Creek at Route 200

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	71.71	80.13	NA	NA	NA
Initial Model Run	74.48	84.83	2.77	4.70	Default Parameter Values
1	71.76	81.05	0.05	0.92	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85%
2	71.17	79.63	-0.54	-0.50	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85% Wind Speed Increase to 4.0 MPH Manning's n Increase to .08

Table H-7. Initial model and calibration results for Elk Creek at the Blackfoot River

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	71.98	77.77	NA	NA	NA
Initial Model Run	75.07	85.57	3.09	7.80	Default Parameter Values
1	72.27	82.80	0.29	5.03	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85%
2	71.60	81.55	-0.38	3.78	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85% Wind Speed Increase to 4.0 MPH Manning's n Increase to .08
3	71.14	78.96	-0.84	1.19	Relative Humidity Decrease to 25%Percent Sunshine Decrease to 85%Wind Speed Increase to 4.0 Manning's n Increase to .08 Thermal Gradient Increased to 2.75

Upper Union Creek Model

The upper Union Creek model simulated temperatures on a 5.4-mile stretch of Union Creek from its headwaters downstream to Potomac Road. Below Potomac Road, Union Creek becomes dewatered. Therefore, modeling on Union Creek below this point was completed in a separate model beginning two miles downstream from Potomac Road. The Upper Union Creek model also includes a tributary, Washoe Creek, which extends for 0.9 miles upstream from its confluence with Union Creek.

Construction
The upper Union Creek model has one point source from a small tributary stream located a half mile downstream from the headwater of the model. This tributary increases flow in Union Creek from 1.2 to 2.4 cubic feet per second (CFS). A second tributary downstream, Washoe Creek, further augments flow by 1.1 CFS. Calibration points for Union Creek are located on Plum Creek Lumber property, above Washoe Creek, and at Potomac Road. Two water diversion points exist for Union Creek, one between the Plum Creek property boundary and Washoe Creek, and one below Washoe Creek.

Modeling of upper Union Creek is for the period July 29, 2006. **Table H-8** lists stream geometry and general vegetation characteristics for the upper Union Creek model. About 30.4 percent of Union Creek streambanks have woody vegetation. Upper Union Creek low flow widths are narrowest near the headwaters and widen to about seven feet by Potomac Road, resulting in an average low flow width of five feet.

Table H-8. Stream conditions for the Upper Union Creek SNTEMP model.

Stream	Modeling Period	Length (mi)	Average Low Flow Width (ft)	Average Bankline Vegetation (%)	Average Shade (%)
Upper Union Creek	July 29, 2006	8.5	5.0	30.4	47.2

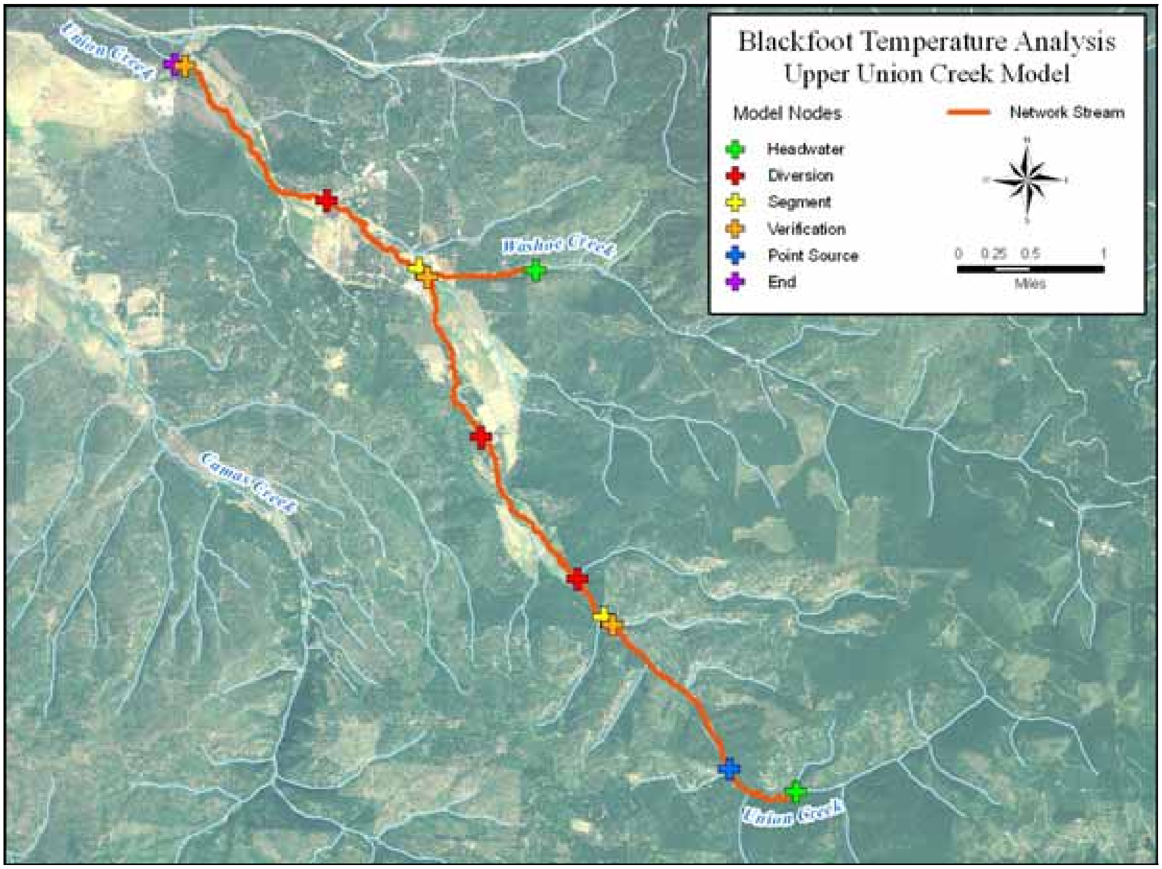

Figure H-2. Schematic of the Upper Union Creek model network and model nodes

Table H-9 lists data input into the model. For each segment and headwater node, flow, width, Manning's-n, and shade must be designated, while water temperature is required for headwater nodes. All other nodes require only water temperature and/or flow data.

Table H-9. Input data for the Upper Union Creek model

Stream	Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Shade (%)	Comments
Union Creek	Headwaters to Plum Creek Boundary	Headwater*	21.6	55.1	1.2	5.5	0.062	42.7	
		Point	21.0	55.4	1.2				Small Tributary near Headwaters
		Calibration	19.5	57.9	2.4				On Plum Creek Property
	Plum Creek to Confluence with Washoe Creek	Segment	19.4		2.4	2.5	0.062	61.7	
		Diversion	17.6		1.2				
		Calibration	16.3	57.7	1.2				Immediately above Washoe Creek
	Washoe Creek to Potomac Road	Segment	16.2		2.3	5.1	0.062	34.6	Confluence with Washoe Creek
		Diversion	15.1		1.8				
		Calibration	13.2	67.0	0.5				Above Potomac Road
		End	13.1		0.5				At Potomac Road
Washoe Creek	To the Mouth at Union Creek	Headwater*	17.1	62.8	1.1	4.2	0.062	30.0	One Mile above Confluence with Union Creek
		End	16.2		1.1				Confluence with Union Creek

Meteorological data for the modeling period July 29, 2006 were summarized and input into the model (**Table H-10**). The summarized data represent hot and dry conditions that cause water temperature extremes. The average daily mean temperature, 75^{o} F, represents a hot period in the summer of 2006.

Table H-10. Meteorological input data for the Upper Union Creek SNTEMP model

Modeling Period	Air Temperature (F) (mean)	Relative Humidity (%) (mean)	Wind (mph) (mean)	Possible Sun (%)	Dust Coefficient	Ground Reflectivity
July 29, 2006	75	33	5.1	90	0.05514	0.28243

Calibration

The upper Union Creek model required little calibration. The initial model run for Union Creek simulated mean daily temperatures 2.66^{o} F, 2.94^{o} F, and 2.09^{o} F greater than observed temperatures at the Plum Creek site, above Washoe Creek, and at Potomac Road, respectively (**Tables H-11 through H-13**). Therefore, calibration was required for the entire model.

To calibrate the model, relative humidity was decreased to 25 percent and sunshine was decreased to 80 percent. This resulted in mean daily temperatures at Potomac Road that were within the 0.9^{o} F margin for calibration, 0.36^{o} F lower than the observed temperature. However, the simulated mean temperature at the other two sites was still too high. Increasing wind speed to 6.7 mph lowered temperatures further, yielding simulated mean daily temperatures within the margin for calibration for all sites.

To improve the model’s performance for maximum temperature, Manning’s n was increased from 0.062 to 0.080 for the segment above the Plum Creek boundary in the model. The resulting “speeding up” of the stream lowered simulated maximum temperature by 1.19^{o} F at Plum Creek, 6.53^{o} F above the observed maximum temperature. Further increases in Manning’s n were not input, as higher values for Manning’s n are unrealistic and there is uncertainty in the capability of SNTEMP to predict daily maximum temperatures accurately (Bartholow, 2004).

Table H-11. Initial model and calibration results for Union Creek at Plum Creek Property

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	57.94	61.2	NA	NA	NA
Initial Model Run	60.60	72.63	2.66	11.43	Default Parameter Values
1	59.49	70.68	1.55	9.48	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80%
2	58.93	68.92	0.99	7.72	Relative Humidity Decrease to 23% Percent Sunshine Decrease to 75% Wind Speed Increase to 6.7 MPH
3	58.93	67.73	0.99	6.53	Relative Humidity Decrease to 23% Percent Sunshine Decrease to 75% Wind Speed Increase to 6.7 MPH Manning's n Increase to .08

Table H-12. Initial model and calibration results for Union Creek immediately above Washoe Creek

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	57.72	63.82	NA	NA	NA
Initial Model Run	60.66	68.56	2.94	4.74	Default Parameter Values
1	59.09	66.63	1.37	2.81	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80%
2	58.26	64.56	0.54	0.74	Relative Humidity Decrease to 23% Percent Sunshine Decrease to 75% Wind Speed Increase to 6.7 MPH

Table H-13. Initial model and calibration results for Union Creek at Potomac Rd

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	67.01	79.68	NA	NA	NA
Initial Model Run	69.10	77.79	2.09	-1.89	Default Parameter Values
1	66.65	75.36	-0.36	-4.32	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 85%
2	66.36	75.09	-0.65	-4.59	Relative Humidity Decrease to 23% Percent Sunshine Decrease to 75% Wind Speed Increase to 6.7 MPH

Lower Union Creek Model

The lower Union Creek model simulated temperatures for an 11.1-mile stretch of Union Creek from the Hall property line below Potomac Road to the confluence with the Blackfoot River. Upstream from the Hall property line, from below Potomac Road downstream to where Union Creek initially crosses Route 200, Union Creek is dewatered. Replenishment of Union Creek occurs below Route 200 by groundwater recharge and a series of springs.

Construction
The lower Union Creek model has three different point sources contributing water throughout the network (**Figure H-3**). The first is a small spring located just downstream from the headwater of the model. This spring contributes relatively cold water at 52.7^{o} F, and doubles the flow in Union Creek from 0.9 cfs to 1.8 cfs. The second point source is Camas Creek, located 1.7 miles downstream from the headwater. Camas Creek contributes a significant amount of flow to Union Creek, increasing flow from 1.8 CFS to 4.2 CFS. The last point source is Ashby Creek and related return flow from irrigation activities, located about 2.2 miles downstream from the Camas Creek input. Calibration points for Union Creek are located at Route 200, at Morrison Road, and 0.3 miles above the mouth to the Blackfoot River. There are two water diversions present on lower Union Creek, both immediately below Morrison Road. These diversions remove a large proportion water from Union Creek, decreasing Union Creek flow from 4.2 CFS to 1.2 CFS.

Modeling of lower Union Creek is for the period July 22, 2006. **Table H-14** lists stream geometry and general vegetation characteristics for the lower Union Creek model. On average, about 12.1 percent of Union Creek streambanks have woody vegetation. Union Creek low flow widths average 9.2 feet, with some excessively widened sections present below Morrison Road.

Table H-14. Stream conditions for the Lower Union Creek SNTEMP model.

Stream	Modeling Period	Length (mi)	Average Low Flow Width (ft)	Average Bankline Vegetation (%)	Average Shade (%)
Upper Union Creek	July 22, 2006	11.1	9.2	12.1	25.9

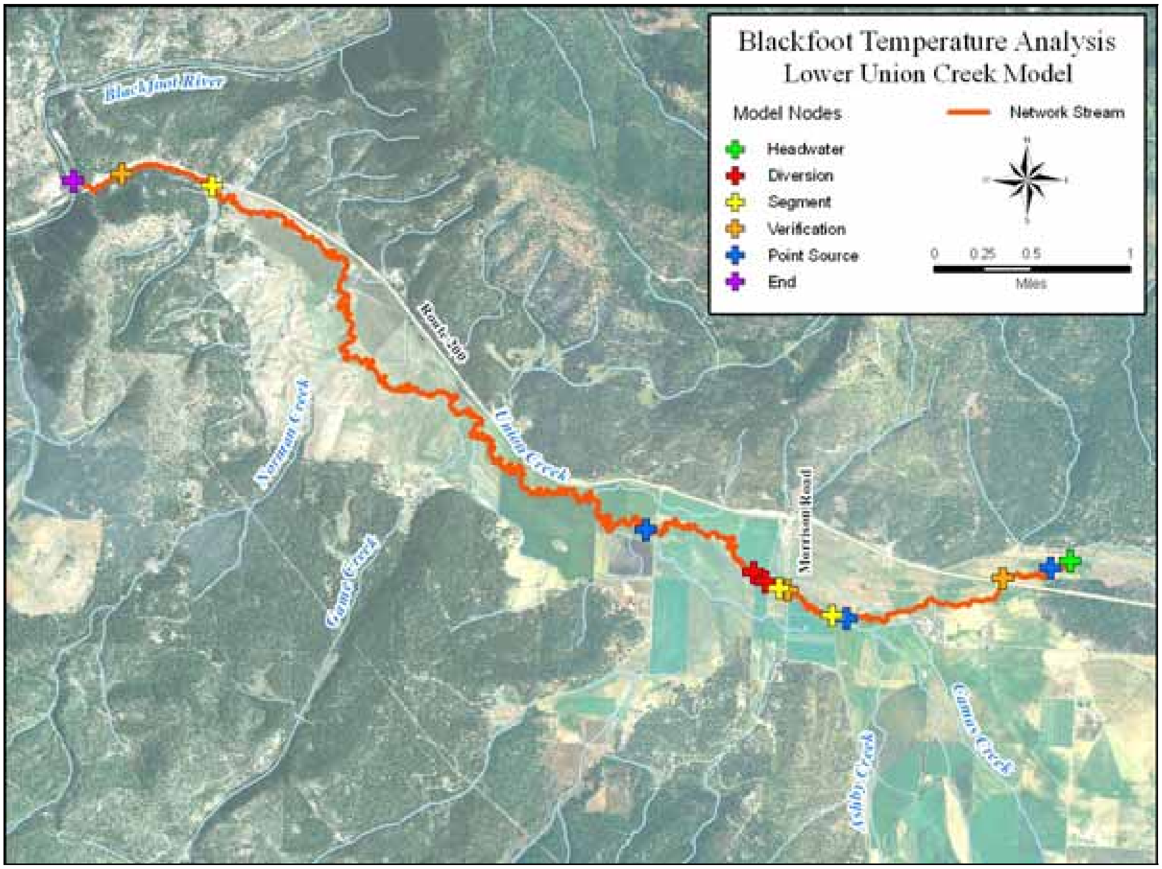

Figure H-3. Schematic of the Lower Union Creek model network and model nodes

Table H-15 lists data input into the model. For each segment and headwater node, flow, width, Manning's-n, and shade must be designated, while water temperature is required for headwater nodes. All other nodes require only water temperature and/or flow data.

Table H-15. Input data for the Lower Union Creek model

Stream	Segment	Node	Stream Mile	Water Temperature (F)	Flow (cfs)	Stream Width (ft)	Manning's n	Shade (%)	Comments
Union Creek	Bill Hall's Land to Camas Creek	Headwater*	11.1	59.0	0.9	4.6	0.062	38.1	Bill Hall's Property Boundary
		Point	11.0	52.7	0.9				Spring on Hall's Land
		Calibration	10.5	56.7	1.8				At Route 200
		Point	9.4	60.4	2.3				Camas Creek Confluence
	Camas Creek to Morrison Road	Segment	9.4		4.2	8.6	0.062	28.7	
		Calibration	8.8	60.8	4.2				At Morrison Road
	Morrison Road to 0.8 Miles above Blackfoot River	Segment	8.8		4.2	9.5	0.062	23.8	At Morrison Road
		Diversion	8.7		1.5				
		Diversion	8.5		1.5				
		Point	7.2	68.0	0.2				Ashby Creek and Return Flow
	To Blackfoot River	Segment	0.8		1.4	16.2	0.062	18.9	Significant Change in Land Cover and Stream Morphology
		Calibration	0.3	74.0	1.4				
		End	0.0		1.4				Mouth to Blackfoot River

Meteorological data for the modeling period July 22, 2006 were summarized and input into the model (**Table H-16**). These data are representative of hot and dry conditions that cause water temperature extremes. The average daily mean temperature, 75^o F, represents a hot period in the summer of 2006.

Table H-16. Meteorological input data for the Lower Union Creek SNTEMP model

Modeling Period	Air Temperature (F) (mean)	Relative Humidity (%) (mean)	Wind (mph) (mean)	Possible Sun (%)	Dust Coefficient	Ground Reflectivity
July 22, 2006	75	33	2.3	90	0.05514	0.28243

Calibration

The lower Union Creek model required little calibration. The initial model run for Union Creek simulated mean daily temperatures 3.34^o F, 4.32^o F, and 3.78^o F greater than observed temperatures at Route 200, Morrison Road, and at the mouth, respectively (**Tables H-17 through H-19**).

To calibrate the model, relative humidity was decreased to 25 percent and sunshine was decreased to 80 percent. This resulted in mean daily temperatures that were still higher than actual measured temperatures. Increasing wind speed to 5.6 mph lowered temperatures further, yielding simulated mean daily temperatures within the margin for calibration for all sites.

To improve the model's performance for maximum temperature, Manning's n was increased from 0.062 to 0.080 for all segments in the model. The resulting "speeding up" of the stream lowers simulated maximum temperature at all sites. However, simulated temperatures are still higher than the margin for calibration. Further increases in Manning's n did not occur for any of the segments in the model.

Table H-17. Initial model and calibration results for Union Creek at Route 200

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	56.7	62.26	NA	NA	NA
Initial Model Run	60.04	78.85	3.34	16.59	Default Parameter Values
1	59.40	76.95	2.70	14.69	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80%
2	57.40	69.89	0.70	7.63	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH
3	57.40	68.07	0.70	5.81	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH Manning's n - Increase to .80

Table H-18. Initial model and calibration results for Union Creek at Morrison Lane

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	60.78	68.36	NA	NA	NA
Initial Model Run	65.10	80.31	4.32	11.95	Default Parameter Values
1	63.36	77.85	2.58	9.49	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80%
2	61.18	71.38	0.40	3.02	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH
3	61.18	69.94	0.40	1.58	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH Manning's n - Increase to .80

Table H-19. Initial model and calibration results for Union Creek at the mouth to the Blackfoot River

Calibration Iteration	Temperature (F)		Difference from Observed Temp (F)		Parameter Changed
	Mean	Max	Mean	Max	
Observed Temperature	74.03	82.35	NA	NA	NA
Initial Model Run	77.81	88.32	3.78	5.97	Default Parameter Values
1	75.24	85.86	1.21	3.51	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80%
2	73.62	85.86	-0.41	3.51	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH
3	73.62	85.08	-0.41	2.73	Relative Humidity Decrease to 25% Percent Sunshine Decrease to 80% Wind Speed Increase to 5.6 MPH Manning's n - Increase to .80